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U1S S1839 S1840 S1854

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GB 2225742 A

(58) Field of search
UK CL (Edition K) B5A AT11P AT9P
INT CL[5] B29C

(54) **Cellular structural component**

(57) A structural component including a structural cellular core for use in highly loaded structures such as those required on aircraft is constructed by (i) providing a plurality of mandrels (12), (ii) wrapping those mandrels in fibre reinforced thermosetting or thermoplastic material (10), (iii) arranging the wrapped mandrels in such a manner as to produce a charged mandrel assembly in which no two opposed faces of any two adjacent mandrels are without an intervening layer or layers of core material, (iv) subjecting the charged assembly to a consolidation treatment to bring the core material into a consolidated state and (v) removing the mandrels to produce the structural cellular core. A skin or skins can be bonded to the core so as to close off the core at one or both ends either by attaching skins to the consolidated core or including skin material in the consolidation treatment.

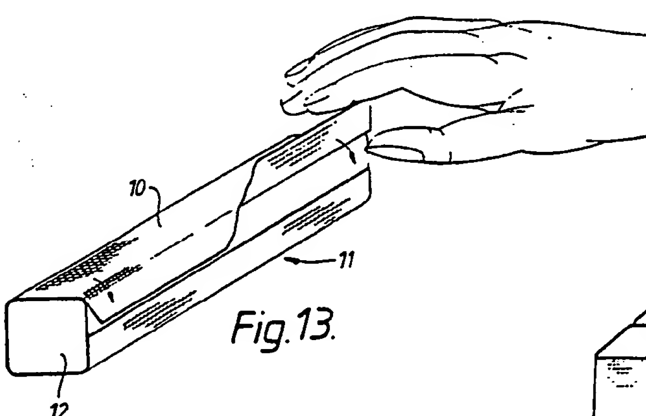

Fig.13.

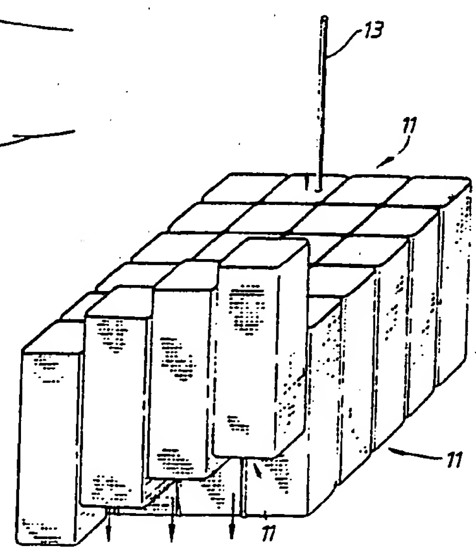

Fig.14.

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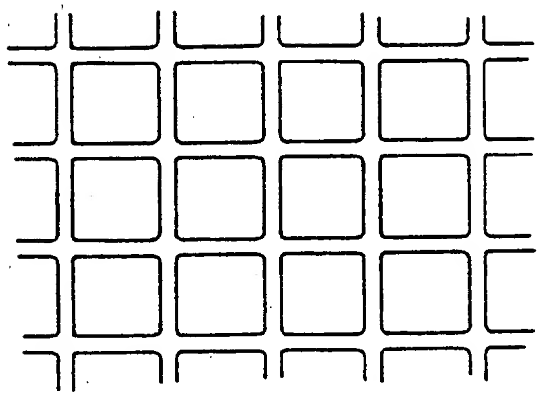


Fig.1.

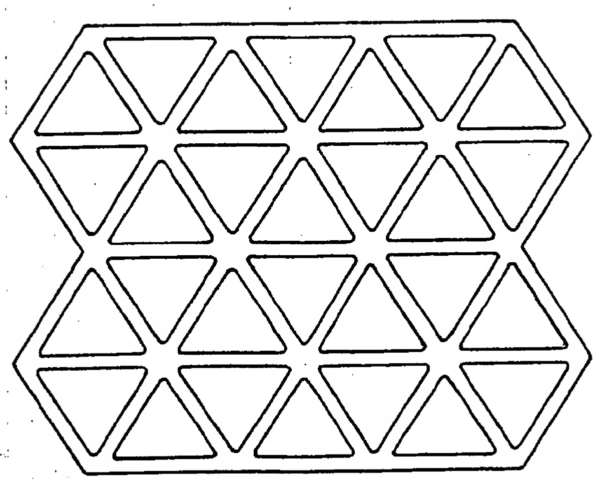


Fig.2.

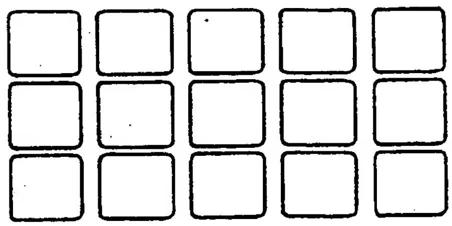


Fig.3.

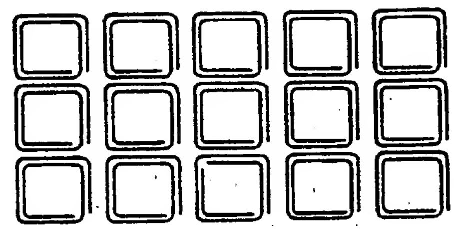


Fig.4.

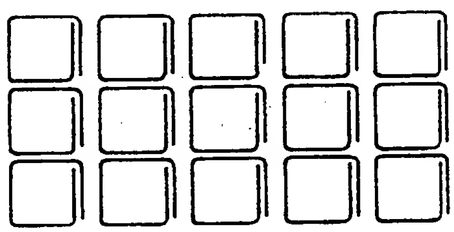


Fig.5.

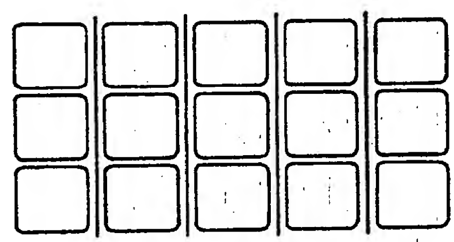


Fig.6.

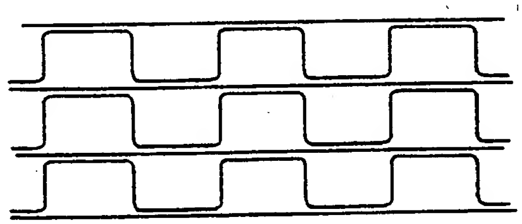


Fig.7.

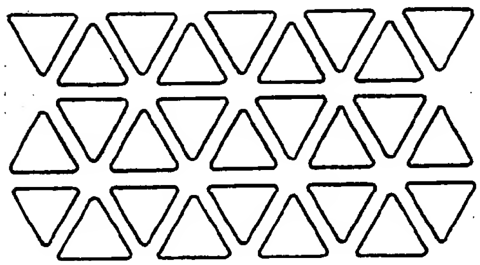


Fig.8.

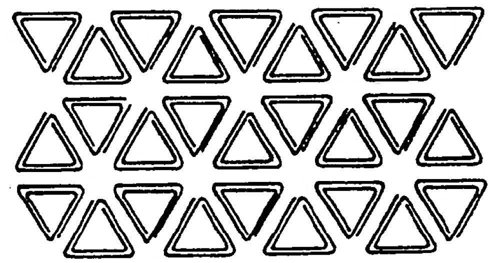


Fig.9.

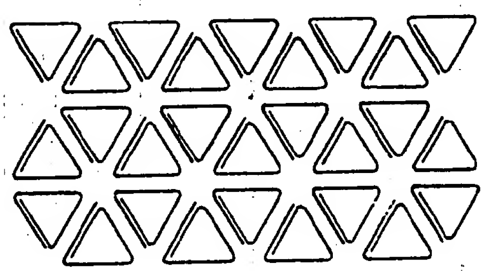
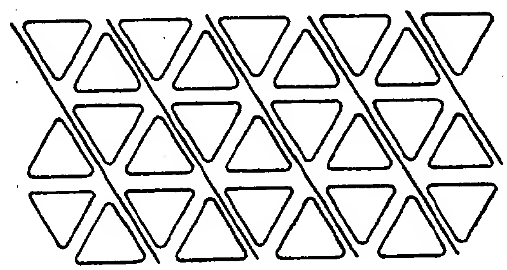


Fig.10.



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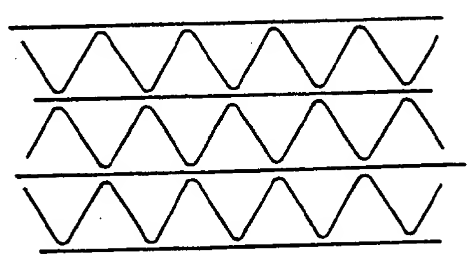


Fig.12.

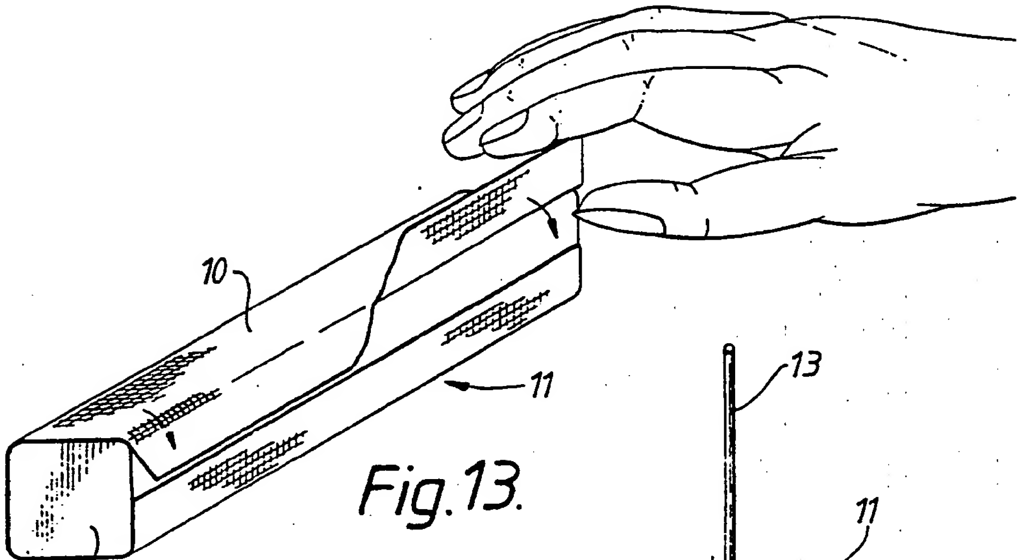


Fig.13.

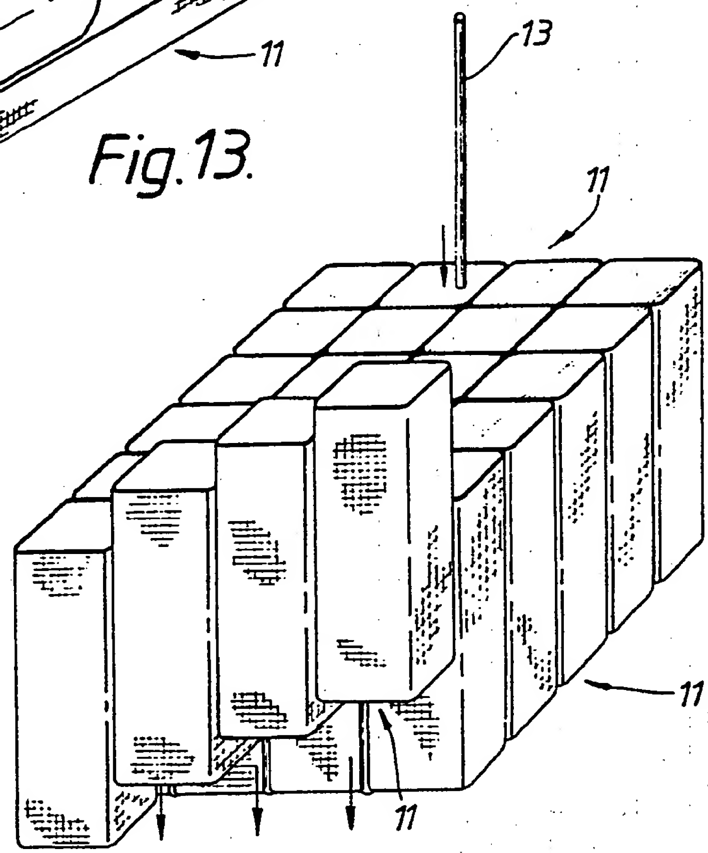


Fig.14.

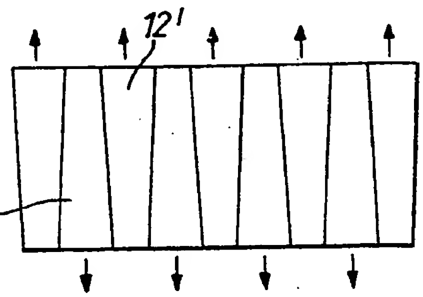


Fig.15.

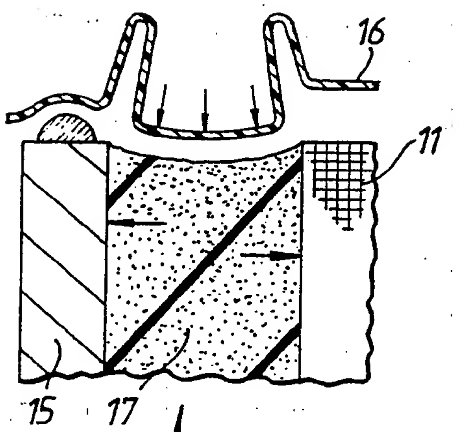
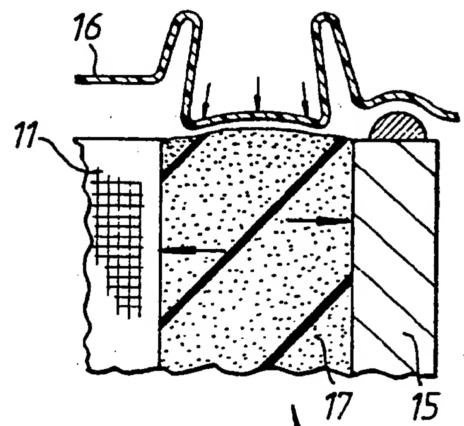


Fig.17.



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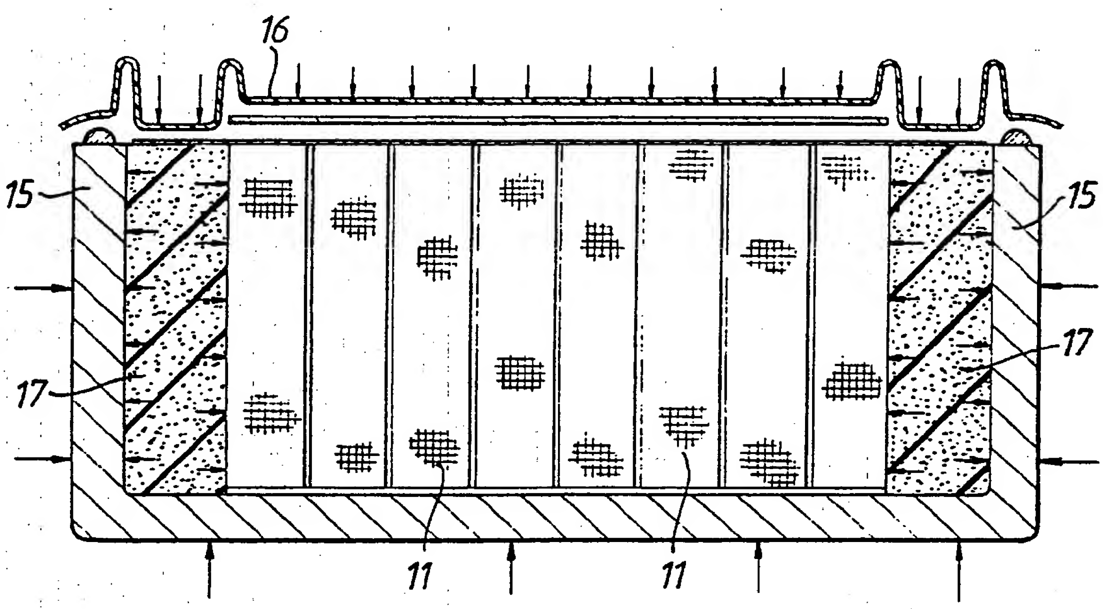

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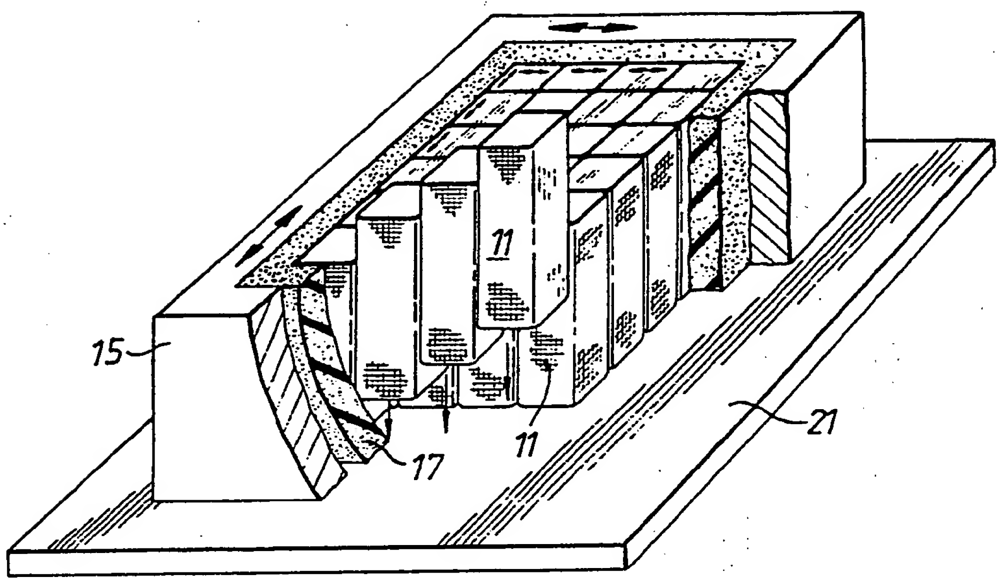

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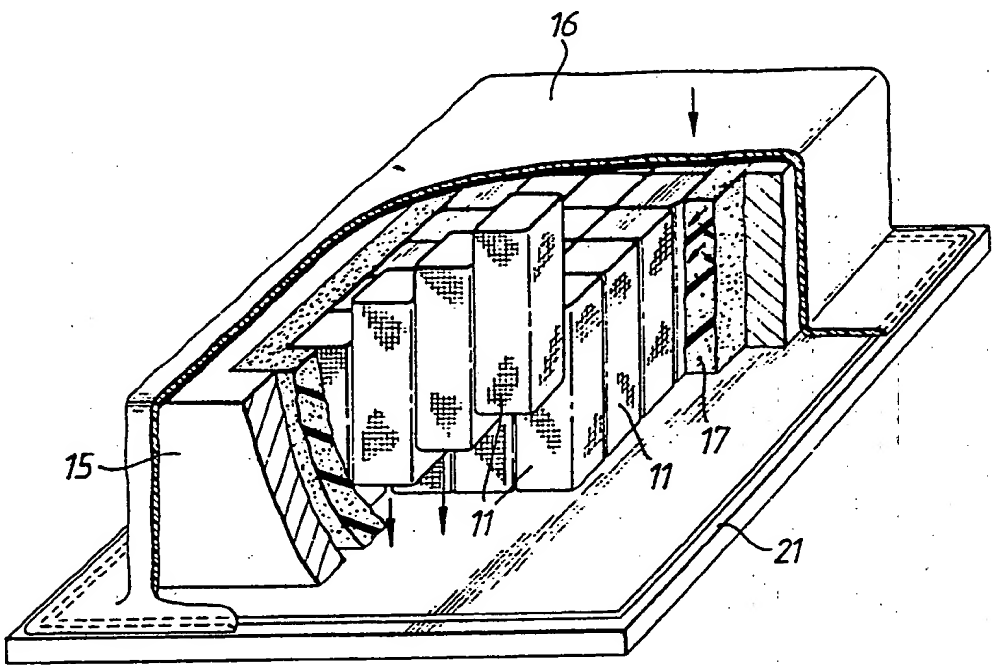

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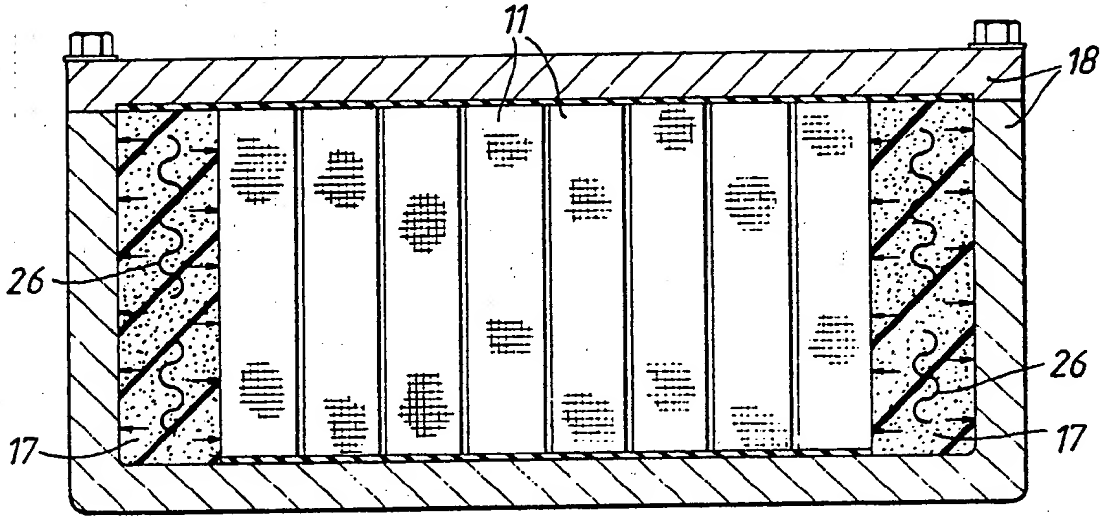

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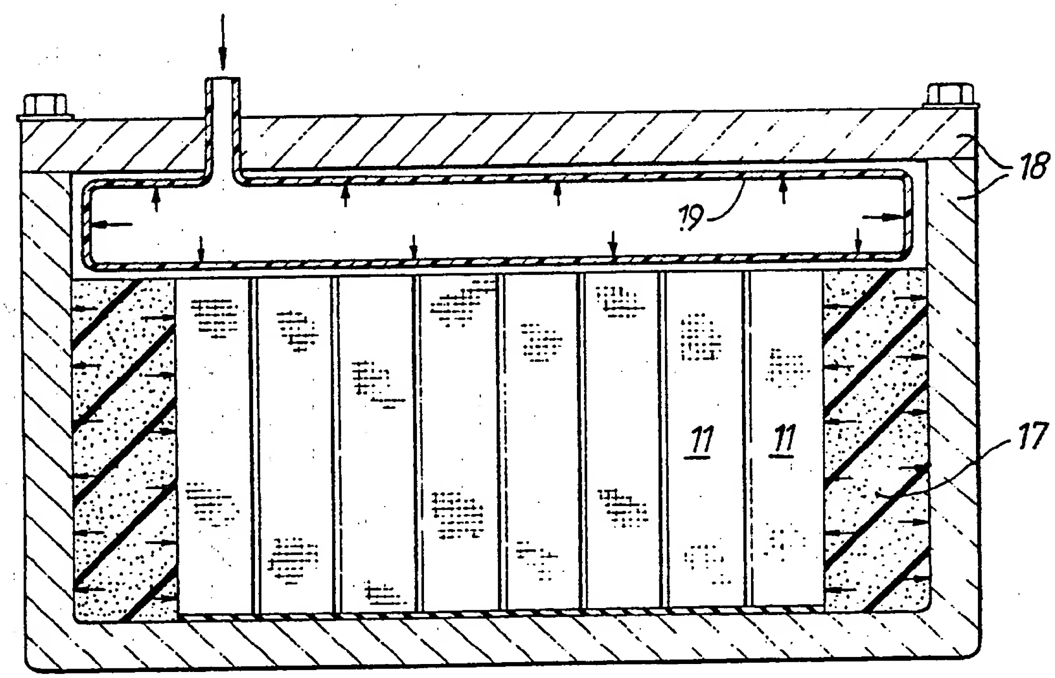

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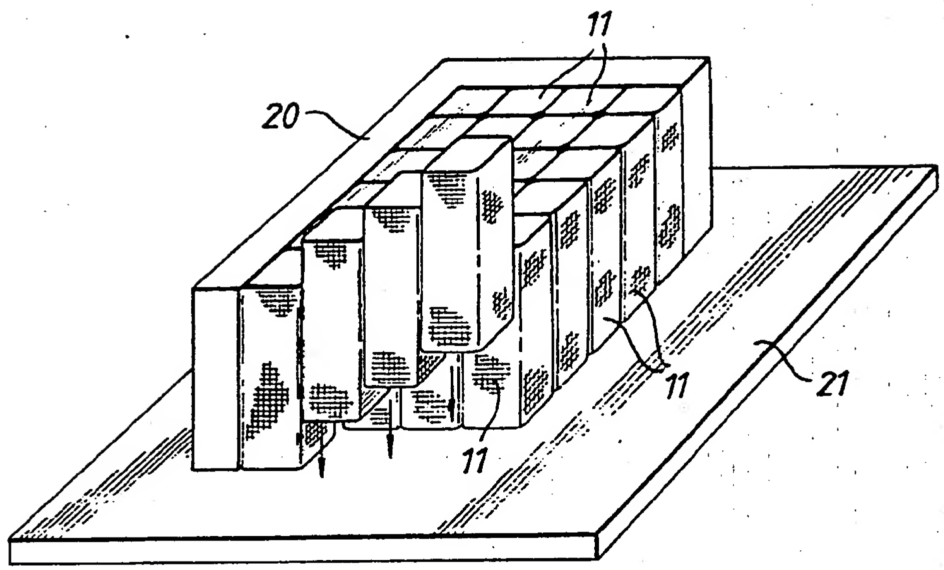
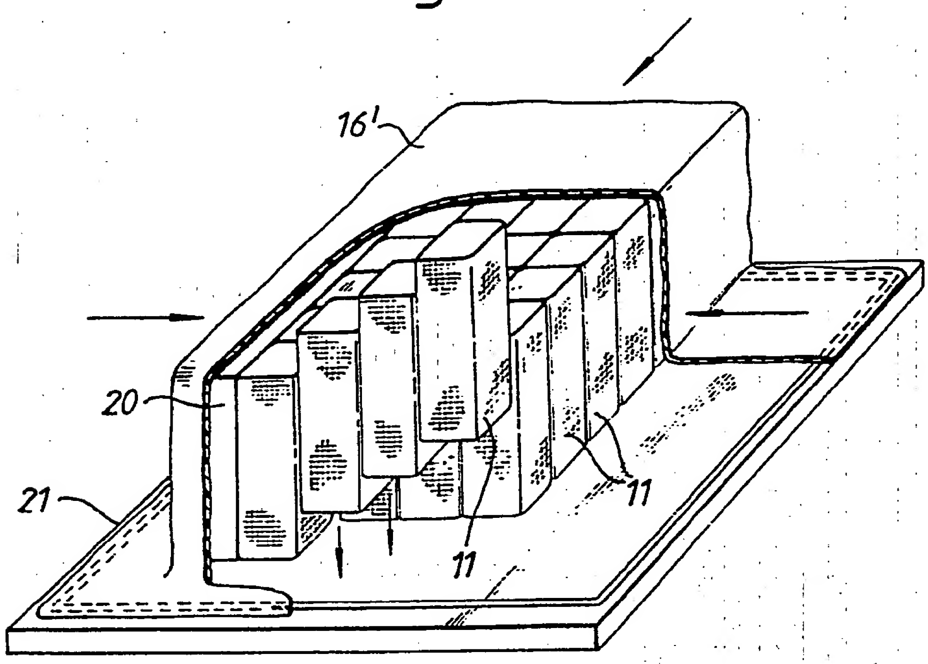


Fig.23.



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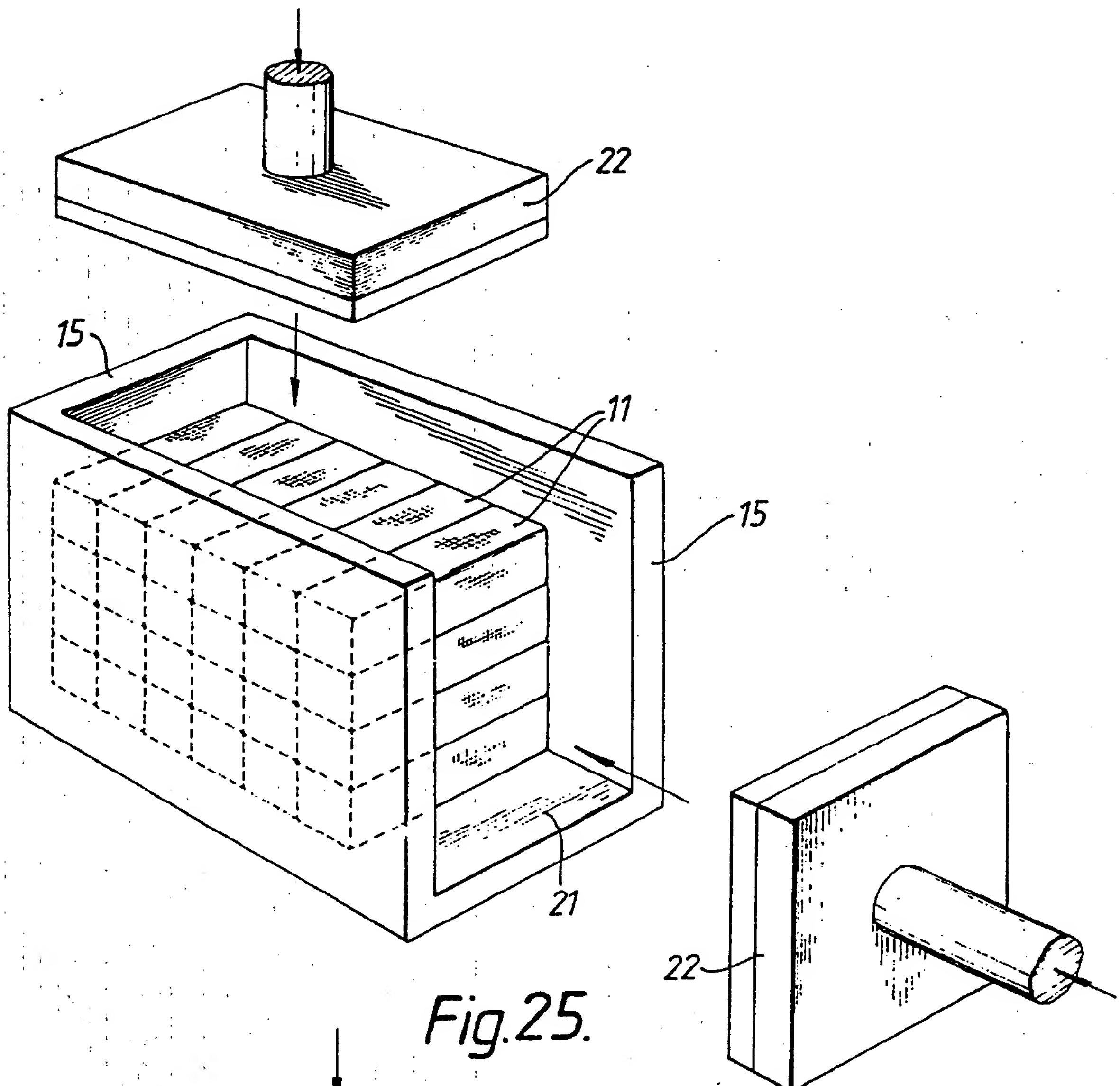

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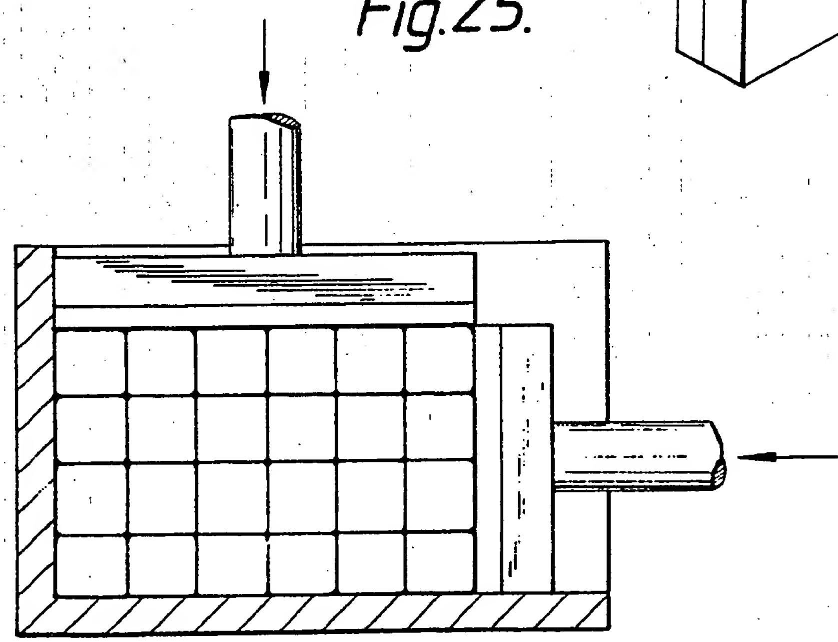

Fig.26.

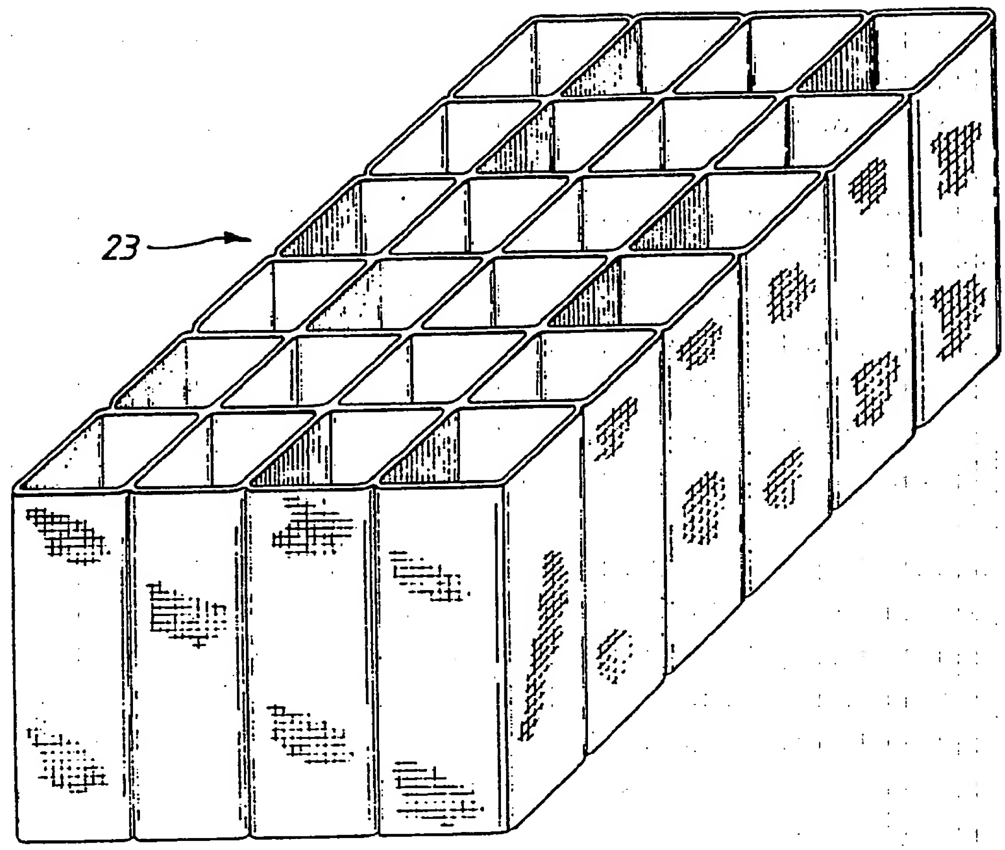

Fig. 27.

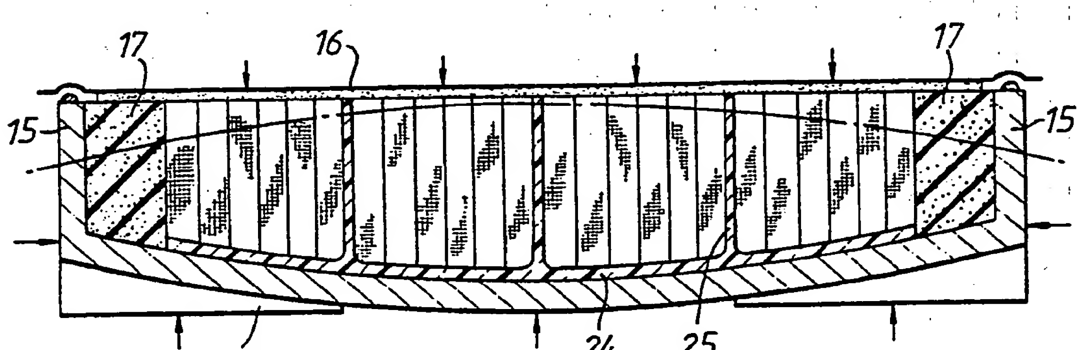

Fig. 28.

Structural Component

The present invention relates to structural components including structural cellular cores and to methods of making such components and cores and is particularly although not exclusively concerned with the manufacture of lightweight structural components having a cellular core made from a continuous fibre reinforced plastics material for use in highly loaded structures such as those required on aircraft. The structural component may however in addition to its structural role also be used in other applications, for example, as a noise attenuation panel and as "fly-away" tooling.

According to a first aspect of the invention there is provided a method of producing a structural cellular core comprising the steps of providing a plurality of mandrels having such cross-sections as when juxtaposed produce a mandrel assembly in which each face of each mandrel is opposed to a corresponding face of another mandrel, applying up to the mandrels one or more layers of core material of a fibre reinforced thermoplastic or partly cured thermosetting resin prior to the forming of or while establishing the mandrel assembly in such a manner as to produce a charged mandrel assembly in which no two opposed faces of any two adjacent mandrels are without an intervening layer or layers of core material, subjecting the charged assembly to such treatment as to bring the core material into a consolidated state, and removing the mandrels to produce the structural cellular core.

A single layer of the core material may be applied to each face of each mandrel prior to the forming of or while establishing the charged assembly or more than one layer of core material may be applied to each face of each mandrel prior to the forming of or while establishing the charged assembly.

Core material may also b so applied to each mandrel that one face of each mandrel is provided with an additional reinforcing layer of material with the mandrels being arranged to form the charged assembly in such a manner that the reinforcing layers lie in predetermined reinforcing paths through the core. The reinforcing paths through the core may advantageously be arranged to lie in planes parallel to the mandrel axes and preferably in two intersecting sets of parallel planes parallel to the mandrel axes and the arrangement is preferably such that the reinforcing layers lying in one set of intersecting planes provide reinforcement which is equal to that of the reinforcing layers lying in the other set of intersecting planes.

In one embodiment of the first aspect of the invention as hereinafter to be described, the one or more layers of core material are applied to the mandrels by individually wrapping with strips of core material. The step of applying the one or more layers of core material to the mandrels may then include the step of applying strips of core material to provide additional reinforcing layers of core material along predetermined reinforcing paths through the core.

In another embodiment of the first aspect of the invention as hereinafter to be described the step of applying the one or more layers of core material to the mandrels comprises applying strips of core material to the mandrels such that each strip follows a predetermined path through the assembly in which it provides a layer of core material for one or more faces of each mandrel along the path and another or others of the strips of core material follows or follow a path or paths in which it or they provides or provide a layer of core material for the remaining face or each of the remaining faces of each of the mandrels.

In one specific embodiment of th first aspect of the invention as hereinafter to be described the mandrels are of square cross-section and are arranged in the assembly in side-by-side rows in each of which the mandrels are so arranged as to present coplanar faces on each side of the row, and each row of mandrels has applied to it a first strip which follows a path in which it provides a layer of core material for the two transverse faces of each mandrel and one coplanar face on one side of the row in respect of each alternate mandrel and one coplanar face on the other side of the row for each of the remaining mandrels in the row and a second strip which follows a path in which it provides a layer of core material for the remaining coplanar faces on one side of the row, with the second strip of the next succeeding row providing a layer of core material for the remaining coplanar faces on the other side of the row.

In an alternative specific embodiment of the first aspect of the invention as hereinafter to be described the mandrels are of triangular cross-section and are arranged in the assembly in side-by-side rows in each of which the mandrels are so arranged that alternate mandrels have coplanar faces on one side of the row and the remaining mandrels have coplanar faces on the other side of the row, and each row of mandrels has applied to it a first strip which follows a path in which it provides a layer of core material for the two transverse faces of each mandrel and a second strip which follows a path in which it provides a layer of core material for the coplanar faces on one side of the row, with the second strip of the next succeeding row providing a layer of core material for the coplanar faces on the other side of the row.

In a preferred embodiment of the first aspect of the invention as hereinafter to be described the treatment

includes subjecting the charged assembly to a heating cycle while applying a consolidating force thereto in a direction or directions at right angles to the longitudinal axes of the mandrels.

The consolidating force may be produced by placing the charged assembly within an assembly support in which the assembly can expand by compression of a resilient lining material lining the support and the consolidating force is generated at least in part by expansion of the mandrels during the application of heat to the assembly relative to the expansion of the assembly support. The resilient lining material may then be subjected to a regulating pressure effective to regulate the consolidating force during the heating cycle by compacting the resilient lining material during an initial low temperature part of the heating cycle when the differential expansion is insufficient to produce the required consolidating force and by allowing expansion of the resilient lining material during a high temperature part of the heating cycle when the differential expansion would give rise to excessive pressure.

The assembly support may then comprise a base on which the charged assembly is placed with the axes of the mandrels at right angles to the base, containing walls to surround the assembly with the lining material interposed between the walls and the assembly and cover means extending from the walls over the charged assembly and the lining material.

In some embodiments of the first aspect of the invention as hereinafter to be described the cover means comprises a flexible cover through which the regulating pressure is applied to the lining material. In one specific embodiment, the treatment of the charged assembly is carried out in an autoclav and the resilient lining

material is subjected to autoclave pressure which is applied as the regulating pressure through the flexible cover to the lining material. In another embodiment the cover means includes an inflatable bag which extends across the charged assembly and across the lining material, and a cover plate which holds the inflatable bag in place so that when the bag is inflated to regulating pressure the regulating pressure is applied to the lining material through the bag. In each of these embodiments heat is also applied to the charged assembly.

In yet another embodiment of the first aspect of the invention as hereinafter to be described the cover means comprises a cover plate closing off the charged assembly and the lining material. The lining material may then include auxiliary heating means.

The assembly support may alternatively comprise a base upon which the charged assembly is placed with the axes of the mandrels parallel to the base, upstanding walls extending from the base and closing off the opposite ends of the charged assembly, a rear end wall closing off a rear side face of the assembly, and top and side hydrostatic rams for applying through interposed resilient lining material regulating pressure to the upper side face and the front side face of the charged assembly. The lining material may then include auxiliary heating means.

In order to facilitate the treatment, the mandrels may also contain integral heating elements.

Preferably, each mandrel has a cross-section which is of the same polygonal form along its length. By "polygonal form" is meant a figure having three or more sides. Each mandrel may be of constant cross-section throughout its length or reduce in cross-section along its length to

facilitate removal of the mandrel from th consolidated core material. Furthermore, the mandrels may be so arranged in the assembly and be of such polygonal form that the mandrels having their larger end faces uppermost are juxtaposed to mandrels having their smaller end faces uppermost. In addition, the mandrels have a coating of release agent or release film to facilitate removal of them from the consolidated core material.

In some embodiments of the first aspect of the invention, each of the mandrels or each of a predetermined number of the mandrels is at least partly composed of fusible material and is removed from the consolidated core material by melting the fusible material.

In other embodiments of the first aspect of the invention, each of the mandrels or each of a predetermined number of the mandrels is at least partly composed of a soluble material and is removed from the consolidated core material by washing with a jet of solvent.

In other embodiments of the first aspect of the invention, each of the mandrels or each of a predetermined number of the mandrels is at least partly composed of erodible material and is removed from the consolidated core material by eroding the erodible material.

The method according to the first aspect of the invention may advantageously include the additional step of bonding a skin or skins to the core so as to close off the core at one or both ends thereof and may also include the step of applying a layer of skin material so as to produce a charged assembly in which the polygonal end faces of the mandrels and the intervening core material contact the skin material, whereby treatment of the charged assembly

produces a consolidated structural component in which the cells at one end of the cellular core are closed by the skin.

The method according to the first aspect of the invention may further include the additional steps of applying a first skin to the assembly support as the first stage in assembling the charged assembly, and incorporating into the charged assembly such material that strengthening spars parallel to the mandrel axes and attached to the first skin are formed during the consolidation treatment to provide an intermediate structural component having a lightweight core with a first skin and integral spars. There may also be included the additional steps of machining the exposed surface of the consolidated intermediate structural component to a predetermined shape, and then attaching a second skin to the exposed surface to close off the core at the other end to form a final structural component.

According to a second aspect of the present invention, there is provided a structural cellular core formed by wall portions which provide bounding faces for a plurality of cells of polygonal cross-section in such arrangement that each wall portion provides a bounding face for two adjacent cells, characterised in that the wall portions are part of a continuous wall structure formed from a core material of a fibre reinforced thermoplastic or part cured thermosetting resin, which is then treated to bring it into a consolidated state.

According to a third aspect of the invention, there is provided a structural component comprising a cellular core according to the second aspect of the invention and a skin closing off the cellular core at one end thereof and co-cured thereto when the core is formed. A further skin may then be provided which closes off the core at

the other end thereof.

According to a fourth aspect of the present invention there is provided an aircraft airframe structural element such as a wing in which the element is formed by a component according to the third aspect of the invention with the skins providing outer surfaces for the element and the core serving as a structural part of the element.

Embodiments of the invention according to its different aspects will now be described by way of example with reference to the accompanying drawings in which:-

Figs 1 and 2 are schematic plan views of cellular cores constructed to orthogrid and isogrid patterns.

Fig 3 is a schematic plan view of an assembly of mandrels of square cross-section which have been wrapped with a single layer of core material and which are arranged in an assembly for producing an orthogrid pattern cellular core.

Fig 4 is a schematic plan view of an assembly of mandrels of square cross-section which have been wrapped with a double layer of core material and which are arranged in an assembly for producing an orthogrid pattern cellular core.

Fig 5 is a schematic plan view of an assembly of mandrels of square cross-section which have been wrapped with core material, such that an overlap provides an additional reinforcing layer of material on one face of each mandrel, and which are arranged in the assembly in such a manner that the overlaps provide reinforcement of an orthogrid pattern cellular core along a series of parallel planes parallel to the mandrel axes.

Fig 6 is a schematic plan view of an assembly of mandrels of square cross-section which have been wrapped with a single layer of core material and in which strips of core material are applied to provide additional reinforcing layers of core material, to provide reinforcement of an orthogrid pattern cellular core along a set of parallel planes parallel to the mandrel axes.

Fig 7 is a schematic plan view of an assembly of mandrels of square cross-section which have been wrapped with core material in the form of continuous strips and which are arranged in the assembly for producing an orthogrid pattern cellular core.

Fig 8 is a schematic plan view of an assembly of mandrels of triangular cross-section which have been wrapped with a single layer of core material and which are arranged in the assembly for producing an isogrid pattern cellular core.

Fig 9 is a schematic plan view of an assembly of mandrels of triangular cross-section which have been wrapped with a double layer of core material and which are arranged in the assembly for producing an isogrid pattern cellular core.

Fig 10 is a schematic plan view of an assembly of mandrels of triangular cross-section which have been wrapped with core material such that an overlap provides an additional reinforcing layer of material on one face of each mandrel, and which are arranged in the assembly such that the overlaps provide reinforcement of an isogrid pattern cellular core along two intersecting sets of parallel planes parallel to the mandrel axis, with the reinforcement provided in one set of intersecting planes being equal to the reinforcement provided in the other set of intersecting planes.

Fig 11 is a schematic plan view of an assembly of mandrels of triangular cross-section which have been wrapped with a single layer of core material and in which strips of core material are applied to provide additional reinforcement of an isogrid pattern cellular core along a series of parallel planes parallel to the mandrel axis.

Fig 12 is a schematic plan view of an assembly of mandrels of triangular cross-section which have been wrapped with core material in the form of continuous strips and which are arranged in the assembly for producing an isogrid pattern cellular core.

Fig 13 is a perspective view of an single mandrel of square cross-section which is being manually wrapped in core material.

Fig 14 is a schematic perspective view illustrating the step of forming the wrapped mandrels into a charged assembly for producing an orthogrid pattern core.

Fig 15 is a schematic cross-sectional side elevation of an assembly of mandrels, which reduce in cross-section along their length and which are arranged such that alternate mandrels have their larger end faces uppermost.

Fig 16 is a schematic cross-sectional side elevation of an assembly support for a charged assembly for use when subjecting the charged assembly to a consolidating treatment in an autoclave.

Fig 17 is a scrap view of part of the assembly support shown in Fig 16 during an initial stage in the consolidating treatment.

Fig 18 is a further scrap view of part of the support

shown in figure 16 during another stage of the consolidating treatment.

Fig 19 is a schematic perspective view of the assembly support shown in Fig 16, partly cut away and revealing the establishment of the charged assembly within the support.

Fig 20 is a further schematic perspective view corresponding to that shown in Fig 19 with the addition of a vacuum closure bag for use in a treatment autoclave.

Figs 21 and 22 are schematic cross-sectional side elevations of two further alternative assembly supports for use in the consolidating treatment of charged assemblies.

Figs 23 and 24 are schematic perspective views illustrating a further assembly support and showing the successive stages in establishing the charged assembly and applying consolidating forces thereto.

Fig 25 is a schematic perspective view illustrating an assembly support where a consolidating pressure is applied using hydrostatic rams.

Fig 26 is a cross-sectional side elevation of the assembly support shown in Fig 25.

Fig 27 is a schematic perspective view of a cellular core produced from a charged assembly of mandrels of square cross-section in which the core material has been subjected to consolidating treatment in any of the assembly supports illustrated in Figs 16 to 26.

Fig 28 is a schematic cross-section of a further assembly support, shown supporting a charged assembly for

producing a structural component for an aircraft.

Referring to the drawings, in one method according to the invention, which is illustrated in Fig 3, core material 10 of a fibre reinforced thermoplastic or partly cured thermosetting resin is manually wrapped around mandrels 12 of square cross-section thus forming individual cells. The wrapping technique is simple and allows scope in the type of product obtained in that many configurations illustrated in Figs 3 to 12 can be produced. Where the core material is thermoplastic, it may be necessary to tack plies of core material together, when forming the charged assembly, using a localised heating device. However, thermoplastic core material is more suited to automated techniques of lay-up.

The cellular core is produced by consolidation of core material in a charged assembly. The charged assembly is produced, as shown in Fig 14, by locating a series of wrapped mandrels 11 together to form a block such that all the mandrel axes are parallel. Additional core material may be applied in strips during formation of the charged assembly in order to provide structural improvement in a preferred direction. Additional material 13 may also be added to fill gaps formed where core mandrels intersect.

Consolidation of the core material is achieved by applying heat and controlled pressure normal to the mandrel axes. As the elevated temperature is reached, the core material bonds (thermoplastic) or co-cures (thermoset) together to form the lightweight core. The tooling and bag-up used during this consolidation treatment is designed to prevent matrix loss during consolidation.

The core mandrel material is chosen such that it will

expand slightly on heating, during the consolidation treatment, to facilitate removal upon cool down. Removal on cool down may also be facilitated by using for example and as shown in Fig 15 tapered mandrels 12',12'' which would be fitted together such that the tapers interlock. The particular method of consolidation chosen depends on whether the core is thermoset or thermoplastic based. The preferred tooling assembly which is designed for autoclave use for a thermoset based core is illustrated in Figs 16 to 18, 19 and 20.

The core material forming the cell walls is consolidated by forces generated through the differential of coefficients of thermal expansion between the peripheral tool assembly 15 and the internal tooling, ie the mandrels 12.

As the tooling assembly is heated, the trapped internal tooling 12 expands relative to the peripheral tool assembly 15 producing the consolidation effect normal to the mandrel axes.

The top of the open face is closed by a bag 16 for autoclave pressure so as to prevent resin loss and regulate the mandrel consolidation force. In the low temperature stage of a cure cycle, the thermal expansion alone is insufficient to compact the cell walls. However, the pressure acting through the bag 16 and on to silicone pads 17 produces a consolidating force normal to the mandrel axes in excess of that achieved through pure thermal expansion, as illustrated in Fig 17. Conversely during the high temperature part of the cure, too much expansion of the core mandrels 12 would generate excessive pressure. The resilience of the silicone pads 17 means that the expansion of the core causes the rubber 17 to be displaced and it expands at its free end, thus relieving pressure (Fig 18).

As an alternative to autoclave processing, thermoset based cores may also be cured in an oven as shown in Fig 21. Thermal expansion of the mandrels can be used as the sole means of consolidation. Instead of using autoclave pressure on a bag on the top face to increase or reduce pressure, a total trapped tooling assembly 18 is used. With no means of controlling pressure excesses or short falls, this arrangement requires accurate dimensions in design and manufacture.

Alternatively, and as shown in Fig 22, to control pressure in an oven cure, a trapped tool assembly 18 with a gas tight inflatable bag 19 over the top surface can provide pressure regulation similar to that possible in an autoclave. In this case, the pressure used is from a remote source eg, a compressor.

As illustrated in Fig 21, oven cures may be facilitated by the incorporation of internal heating coils 26 into the silicone pads 17 that line the external tooling.

Thermoplastic based cores also require pressure consolidation during application of a heat-up cycle. As a result of the nature of thermoplastic material, a consolidation temperature higher than that for thermosets may be required. While consolidation by thermal expansion of the tooling is still a suitable method of manufacture, it may take a prolonged period in comparison to consolidation of thermosets. An alternative, shown in Fig 23, is to use a core mandrel support assembly similar to the assembly in Fig 16 but with two sides open to allow consolidation by application of hydrostatic pressure (ie autoclave pressure or other external pressure) before and during the heat-up cycle. The external tooling is in the form of a two-walled peripheral mould 20 and a base-plate 21. Controlled pressure may, as shown in Fig 24, be applied to a bagged

set up 16' using an autoclave. Alternatively, controlled pressure may, as shown in Fig 25, be applied normal to the mandrel axis by hydrostatic rams 22.

After consolidation, the charged assembly is removed from the tooling and the mandrels are removed to produce, as shown in Fig 27, the consolidated core 23. Mandrel removal can commence upon cool down when the mandrels 12 have contracted so as to avoid damage to the core 23. To facilitate removal, mandrels 12 are coated with release agents prior to lay-up. Many options of permanent or temporary release films or agents in either a very thin coat or discrete layer are available on the market.

After inspection, the core 23 can be milled or machined in any fashion to the required cell height and profile and cut to the required area. Skins can be applied to the core either after or during a consolidation process to produce a sandwich assembly. The sandwich assembly may be a flat stock panel or a detailed component of particular shape and curvature, including double curvature. Inflexible cores would normally be used in the manufacture of such curved sandwich components but cores with a degree of flexibility can also be used. Skins can be bonded to the core or a core can be consolidated to include skins as shown in Fig 28. For cores based on a thermosetting material, skins may be bonded in a single stage operation or a two stage operation, that is to say, (i) in the single stage operation both skins are bonded to the core 23 by film adhesive or co-cured in a single cure, or (ii) in a two stage operation one skin and core 23 can be bonded by film adhesive or co-cured in the first stage cure and the other skin can then be bonded separately with film adhesive or in a secondary cure. The latter method allows further operations to be performed on the assembly prior to top skin closure, for example addition of

internal detail or accurate milling. A further development of both the one stage and two stage process allows manufacture of whole structural components.

Fig 28 shows an assembly suitable for the production of an integrally stiffened structural component which in this embodiment is a wing box. The base plate 21' of the tooling is curved to the shape required for the lower skin of the wing box. A layer of skin material 24 is first applied to the base plate 21' as the first stage in formation of the charged assembly. Further material is added to form integral spars 25. Consolidation of the assembly thus formed results in a structural component having a cellular core with integral spars bonded to a bottom skin having the desired surface curvature. The mandrels 12 are then removed and the top surface of the cellular core is machined to the appropriate curved shape and a top skin attached thereto to complete the wing box.

Where the core 23 is based on thermoplastic material, the skins may be attached by first remelting the matrix on local areas of the core 23 or the skins or both prior to location. Alternatively, as in the case of thermosets, a film adhesive may be used to bond skins to a core 23 or a skin may be incorporated in the charged assembly prior to the consolidation treatment as in Fig 28.

The core of the present invention is made from fibre reinforced plastic. Suitable fibres include continuous carbon, aramid, boron or glass fibres. The fibres can be arranged unidirectionally or in a woven format such as plain weave, satin, twill or crows foot weaves. Suitable thermosetting resins include epoxy, polyimide, phenolic and polyester resins. Suitable thermoplastic matrix materials include polyether ether ketone, polyether ketone ketone, polyaromatic ketone, polyphenylene sulphide, polyamide-imide, thermoplastic polyimide,

polyether-imide, polyurethane and polyethylene.

It is envisaged that the lay-up of the core material will eventually be automated. The following methods are considered suitable, that is to say:-

(a) by filament winding where wrapping is achieved by revolving the mandrel and which is suitable for both thermoplastic and thermoset core materials,

(b) by spiral winding which is similar to filament winding except that the mandrel does not revolve ie the core material is spiralled around the mandrel as it is drawn along its axis,

(c) by braiding which is similar to spiral winding except that core material is intertwined around the mandrel,

except that localised heating of a thermoplastic matrix or the mandrels may be required.

Where spiral winding or braiding is used for a thermosetting core material, fibres will be wound round the mandrel before impregnation with resin.

Pultrusion and pulwinding are further automated techniques suitable for core material with both thermoset and thermoplastic matrix. Here the core material is pulled from rolls and drawn through a series of forming dies, applying it to a moving mandrel. The reinforcing fibres of the core material could be in woven or unidirectional form. Where thermoplastic core material is used, the dies would typically be heated. In pulwinding, additional reinforcement is provided through spiral winding of the core material.

In all the above automated lay-up techniques, one long mandrel may be formed by the temporary joining of a series of short mandrels. Consequently, automated trimming of the core material (on the mandrel) may be required, except possibly for pultrusion or pulwinding, where it may be possible to lay-up without a mandrel which would be applied after the lay-up had been cut to length.

In the embodiments of the invention hereinbefore described, the mandrels around which the core material is wrapped may be constructed from a wide variety of materials. Suitable materials include for example elastomeric materials such as silicone rubber and polyacrylic rubber, plastic materials such as PTFE and FEP, metallic materials such as for example aluminium alloy and steel, ceramic materials such as Al O_3 and composite materials such as carbon composite and glass composite. Mandrels constructed from such materials are re-usable and are withdrawn from the consolidated core material in solid form.

Alternatively, fusible mandrels may be constructed from materials such as, for example, eutectic salt, eutectic metal or wax. Fusible mandrels may be melted out of the consolidated core material at a temperature which is sufficient to melt the mandrels but is not detrimental to the consolidated core material.

Fusible mandrels are particularly suited to automated lay-up techniques since one long mandrel may be wrapped with core material and split into individual wrapped mandrels using methods which can cut through both the core material and the fusible mandrel material. Examples of suitable methods include trimming using a blade, hot wire or laser.

Hybrid mandrels may also be constructed which have a re-usable mandrel backbone surrounded by fusible mandrel material. Hybrid mandrels are removed from the consolidated core material by melting the fusible material and removing the re-usable backbone.

Mandrels may also be constructed from soluble material such as washout plaster. Soluble mandrels are removed from the consolidated core material using a high pressure solvent jet to erode the solid mandrel without damaging the consolidated core material.

In addition each mandrel may be constructed to include an integral heating element to facilitate the consolidation treatment.

The structural cores produced according to the embodiments of the invention as hereinbefore described, have several advantages over known structural core systems.

In particular, a honeycomb structural panel is currently in use in the production of many sandwich components, with the organic aramid (aromatic polyamide) commonly being used in fibre paper form to construct the honeycomb core. The present invention allows configurations to be obtained which are more structurally efficient than the aromatic polyamide fibre paper honeycomb structure and the configuration of the core can be tailored according to the loads which it will have to bear, unlike the fibre paper structure. The cellular core of the present invention is more temperature resistant than the fibre paper structure and moisture up-take is eliminated unlike that of the fibre paper structure.

The cellular core of the present invention is lighter and

a flexural modulus can be attained which is higher than that for cellular cores currently used. It is more damage tolerant than known cellular cores and bonds extremely well using current aerospace adhesives. A further advantage is the ability to bond the core to other fibre reinforced components without the need for foam adhesive by using a consolidation method, as for example in bonding the reinforcing spars illustrated in Fig 28. An advantage of the core of the present invention over previously known light alloy honeycomb cores is that it does not exhibit galvanic corrosion.

CLAIMS

1. A method of producing a structural cellular core comprising the steps of providing a plurality of mandrels having such cross-sections as when juxtaposed produce a mandrel assembly in which each face of each mandrel is opposed to a corresponding face of another mandrel, applying up to the mandrels one or more layers of core material of a fibre reinforced thermoplastic or partly cured thermosetting resin prior to the forming of or while establishing the mandrel assembly in such a manner as to produce a charged mandrel assembly in which no two opposed faces of any two adjacent mandrels are without an intervening layer of core material, subjecting the charged assembly to such treatment as to bring the core material into a consolidated state, and removing the mandrels to produce the structural cellular core.

2. A method according to claim 1 wherein a single layer of the core material is applied to each face of each mandrel prior to the forming of or while establishing the charged assembly.

3. A method according to claim 1 wherein more than one layer of core material is applied to each face of each mandrel prior to the forming of or while establishing the charged assembly.

4. A method according to claim 1, 2 or 3 wherein core material is so applied to each mandrel that one face of each mandrel is provided with an additional reinforcing layer of material and wherein the mandrels are arranged to form the charged assembly in such a manner that the reinforcing layers lie in predetermined reinforcing paths through the core.

5. A method according to claim 4 wherein the reinforcing paths through the core lie in planes parallel

to the mandrel axes.

6. A method according to claim 5 wherein the reinforcing paths through the core lie in two intersecting sets of parallel planes, parallel to the mandrel axes.

7. A method according to claim 6, wherein the reinforcing layers lying in one set of intersecting planes provide reinforcement which is equal to that of the reinforcing layers lying in the other set of intersecting planes.

8. A method according to any of the claims 1 to 7, wherein the one or more layers of core material are applied to the mandrels by individually wrapping with strips of core material.

9. A method according to any of claims 1 to 8 wherein the step of applying one or more layers of core material to the mandrels includes the step of applying strips of core material to provide additional reinforcing layers of core material along predetermined reinforcing paths through the core.

10. A method according to any of claims 1 to 8 wherein the step of applying the one or more layers of core material to the mandrels comprises applying strips of core material to the mandrels such that each strip follows a predetermined path through the assembly in which it provides a layer of core material for one or more faces of each mandrel along the path and wherein another or others of the strips of core material follows or follow a path or paths in which it or they provides or provide a layer of core material for the remaining face or each of the remaining faces of each of the mandrels.

11. A method according to claim 10 wherein the mandrels are of square cross-section and arranged in the assembly in side-by-side rows in each of which the mandrels are so arranged as to present coplanar faces on one each side of the row wherein each row of mandrels has applied to it a first strip which follows a path in which it provides a layer of core material for the two transverse faces of each mandrel and one coplanar face on one side of the row for each alternate mandrel and one coplanar face on the other side of the row for each of the remaining mandrels in the row and a second strip which follows a path in which it provides a layer of core material for the remaining coplanar faces on one side of the row.

12. A method according to claim 10 wherein the mandrels are of triangular cross-section and are arranged in the assembly in side-by-side rows in each of which the mandrels are so arranged that alternate mandrels have coplanar faces on one side of the row and the remaining mandrels have coplanar faces on the other side of the row, wherein each row of mandrels has applied to it a first strip which follows a path in which it provides a layer of core material for the two transverse faces of each mandrel and a second strip which follows a path in which it provides a layer of core material for the coplanar faces of on one side of the row and wherein the second strip of the next succeeding row provides a layer of core material for the coplanar faces on the other side of the row.

13. A method according to any of claims 1 to 12 wherein the treatment includes subjecting the charged assembly to a heating cycle while applying a consolidating force thereto in a direction or directions at right angles to the longitudinal axes of the mandrels.

14. A method according to claim 13 wherein the

consolidating force is produced by placing the charg d assembly within an assembly support in which the assembly can expand by compression of a resilient lining material lining the support and wherein the consolidating force is generated at least in part by expansion of the mandrels during the application of heat to the assembly relative to the expansion of the assembly support.

15. A method according to claim 14 wherein the resilient lining material is subjected to a regulating pressure effective to regulate the consolidating force during the heating cycle by compacting the resilient lining material during an initial low temperature part of the heating cycle when the differential expansion is insufficient to produce the required consolidating force and by allowing expansion of the resilient material during a high temperature part of the heating cycle when the differential expansion would give rise to excessive pressure.

16. A method according to claim 15, wherein the assembly support comprises a base on which the charged assembly is placed with the axes of the mandrels at right angles to the base, containing walls to surround the assembly with the lining material interposed between the walls and the assembly and cover means extending from the walls over the charged assembly and the lining material.

17. A method according to claim 16 wherein the cover means comprises a flexible cover through which the regulating pressure is applied to the lining materials.

18. A method according to claim 17 wherein the treatment of the charged assembly is carried out in an autoclave and wherein the resilient lining material is subjected to autoclave pressure which is applied as the regulating pressure through the flexible cover to the lining

material.

19. A method according to claim 16 wherein the cover means includes an inflatable bag which extends across the charged assembly and across the lining material, and a cover plate which holds the inflatable bag in place so that when the bag is inflated to regulating pressure the regulating pressure is applied to the lining material through the bag.

20. A method according to claim 16 wherein the cover means comprises a cover plate closing off the charged assembly and the lining material.

21. A method according to claim 20 wherein the lining material includes auxiliary heating means.

22. A method according to claim 14 wherein the assembly support comprises a base upon which the charged assembly is placed with the axes of the mandrels parallel to the base, upstanding walls extending from the base and closing off the opposite ends of the charged assembly, a rear end wall closing off a rear side face of the assembly, and a top and side hydrostatic rams for applying through interposed resilient lining material regulating pressure to the upper side face and the front side face of the charged assembly.

23. A method according to any of claims 1 to 22 wherein each mandrel has a cross-section which is of the same polygonal form along its length.

24. A method according to claim 23 wherein each mandrel is of constant cross-section throughout its length.

25. A method according to any of claims 1 to 24 wherein each of the mandrels or each of a predetermined number of

them includes an integral heating element to facilitate consolidation of the core.

26. A method according to any of claims 1 to 25 wherein the mandrels have a coating of release agent or release film to facilitate removal of them from the consolidated core material.

27. A method according to any of claims 1 to 25 wherein each of the mandrels or each of a predetermined number of the mandrels is at least partly composed of fusible material and is removed from the consolidated core by melting the fusible material.

28. A method according to claim 27 wherein each of the mandrels or each of a predetermined number of them includes an internal support of non-fusible material.

29. A method according to any of claims 1 to 25 wherein each of the mandrels or each of a predetermined number of them is at least partly composed of a soluble material and is removed from the consolidated core material by washing with a jet of solvent.

30. A method according to any one of claims 1 to 25 wherein each of the mandrels or each of a predetermined number of them is at least partly composed or erodible material and is removed from the consolidated core by eroding the erodible material.

31. A method according to any of claims 1 to 26 wherein each mandrel reduces in cross-section along its length to facilitate removal of the mandrel from the consolidated core material.

32. A method according to claim 31 wherein the mandrels are so arranged in the assembly and are of such polygonal

form that the mandrels having their larger end faces uppermost ar juxtaposed to mandrels having their smaller end faces uppermost.

33. A method according to any of claims 1 to 30 including the additional step of bonding a skin or skins to the core so as to close off the core at one or both ends thereof.

34. A method according to claim 33 including the step of applying a layer of skin material so as to produce a charged assembly in which the polygonal end faces of the mandrels and the intervening core material at one end of the assembly contact the skin material, whereby treatment of the charged assembly produces a consolidated structural cellular core in which the cells at one end of the core are closed by the skin.

35. A method according to claim 34 including the additional steps of applying a layer of skin material to the base of the assembly support as the first stage in assembling the charged assembly, and incorporating into the charged assembly such material that strengthening spars parallel to the mandrel axes and attached to the bottom skin are formed during the consolidation treatment to provide an intermediate structural component having a lightweight core with a bottom skin and integral spars.

36. A method according to claim 35 including the additional steps of machining the upper surface of the consolidated intermediate structural component to a predetermined shape, and then attaching a top skin to close off the core at the upper end to form a final structural component.

37. A structural cellular core produced by a method according to any of claims 1 to 32.

38. A structural component produced by the method according to claims 35 or 36.

39. A structural cellular core formed by wall portions which provide bounding faces for a plurality of cells of polygonal cross-section in such arrangement that each wall portion provides a bounding face for two adjacent cells, characterised in that the wall portions are part of a continuous wall structure formed from a core material of a fibre reinforced thermoplastic or part cured thermosetting resin, which is then treated to bring it into a consolidated state.

40. A structural component comprising a cellular core according to claim 39 and a skin closing off the cellular core at one end thereof and co-cured thereto when the core is formed.

41. A component according to claim 40, comprising a further skin which closes off the core at the other end thereof.

42. An aircraft structural component including a core according to claim 37 or 39.

43. An aircraft structural component according to claim 40 or 41.

44. An aircraft wing in which a part is formed by a component according to claim 38 with the skins providing upper and lower surfaces for the wing and the core serving as a structural part of the wing.

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